

UNITED STATES  
DEPARTMENT OF THE INTERIOR  
GEOLOGICAL SURVEY

WATER-SURFACE ELEVATIONS FOR THE  
HIGH TIDE OF DECEMBER 15, 1977,  
IN THE PUGET SOUND REGION, WASHINGTON

By Leonard M. Nelson

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### METRIC CONVERSIONS

<u>Multiply</u>	<u>by</u>	<u>to obtain</u>
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. Tidal elevations are compared to mean lower low water datum (MLLW), which is lower than NGVD of 1929 by amounts ranging from about 4 to 8 feet, depending on location in the Puget Sound region. Mean lower low water datum (MLLW) is used for the elevations shown in this report.

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ABSTRACT

An unusually high oceanic tide on December 15, 1977, caused flooding of lowlying, nearshore parts of western Washington, including several areas in the Puget Sound region. At Seattle, the December 15 high tide of 14.8 feet above MLLW (mean lower low water datum; 8.55 feet above the National Geodetic Vertical Datum of 1929, or NGVD) was 0.1 foot higher than the 100-year high tide. At Neah Bay, near the western end of the Strait of Juan de Fuca, however, the high tide of 8.77 feet MLLW (4.55 feet NGVD) on that date was 3.2 feet lower than the 100-year high tide. This study has identified the observed December 15, 1977, high-tide elevations at many locations in the Puget Sound region. The observed high tide of that date was much higher than predicted in most of the Puget Sound region, primarily as the result of a very low barometric pressure. Little damage from wind waves was reported. Elevation profiles for the predicted and observed high tides on December 15, 1977, and for several other selected tide levels indicate an increase in the maximum height in the inland direction, except near Port Angeles, and show abrupt changes in tidal elevations at three constrictions - Admiralty Inlet, Tacoma Narrows, and Deception Pass.

## INTRODUCTION

The purpose of this study, done in cooperation with the Land Information and Analysis Office of the Geological Survey, was to document the elevations of the December 15, 1977, high tide at the inland marine shorelines of northwestern Washington. The December 15, 1977, high tide was caused by an unusually low barometric pressure in the Puget Sound region (the National Weather Service measured a daily average barometric pressure of 28.85 inches of mercury at the Seattle-Tacoma Airport on that date). At Seattle the tide equaled the highest on record (February 6, 1904). The documentation of these tide elevations will help to determine flood-prone shorelines and should assist in nearshore land-use planning and coastal flooding mitigation. However, the elevations determined in this study and presented herein do not reflect any increase that might result from wind waves. In some places wind-wave increases can amount to several feet and therefore should be considered when determining flood-prone or safe areas.

The study area includes Puget Sound from Port Townsend to Olympia, passages through the San Juan Islands connecting the Strait of Georgia and the Strait of Juan de Fuca, and the Strait of Juan de Fuca from the Pacific Ocean at Tatoosh Island to Puget Sound at Port Townsend and Deception Pass (figs. 1-3).

## TIDAL-STATION ELEVATIONS

Elevations were obtained from the National Ocean Survey (NOS) for several selected tide levels at tidal stations in the study area. The tide levels are those commonly used and defined in marine navigation books and in NOS tide tables and records. Elevations at tidal stations for two of the levels, mean higher high water and mean tide level, are given in table 1, along with the elevation of the December 15, 1977, high tide at locations where it could be determined. The length of the tidal elevation records used by NOS to determine the tide-level elevations varies from 80 years at Seattle to less than 30 days at many of the stations.

The National Ocean Survey recorded the high-tide elevations in the Puget Sound region on December 15, 1977, at 11 stations—Neah Bay, Port Angeles, Port Townsend, Hansville, Olympia, Tacoma, Seattle, Bremerton, Everett, Friday Harbor, and Cherry Point (figs. 1-3). Tidal elevations for the December 15, 1977, high tide at other sites were obtained from elevation surveys of high-water marks identified by people living along the shorelines. Most of the privately observed elevations are considered reliable and were memorable because the water had entered homes or was about to enter homes. Most observers also recalled little wave action from wind. The observed high-tide elevations for December 15, 1977, are shown in figures 1-3 and table 1.

The elevations used in the Puget Sound region are based on two different datums. Tidal elevations are based on mean lower low water (MLLW) datum, and land-surface elevations are based on the "Sea Level Datum of 1929 through the Pacific Northwest Supplementary Adjustment of 1947" (National Geodetic Vertical Datum or NGVD, formerly Mean Sea Level Datum or MSL). The adjustment from one datum to the other at some locations where both datums are known is given in table 1; that is, elevation in MLLW datum minus the MLLW-to-NGVD adjustment equals the elevation in relation to NGVD at that location.

The December 15, 1977, high-tide elevation was 14.80 feet MLLW (8.55 ft NGVD) at Seattle and equaled the highest tide on record (February 6, 1904). On the basis of a log-Pearson III frequency curve with a skew of +0.2 (Chow, 1964) that fits the annual highest tides recorded over 71 years (1899-1969) at Seattle (fig. 4), this tide elevation was 0.1 foot above the 100-year tide at Seattle.

At Neah Bay, the elevation of the December 15, 1977, high tide was 8.77 feet MLLW (4.55 feet NGVD; fig. 4), which is much less than the highest tide on record (12.00 feet MLLW, or 7.78 feet NGVD, on November 30, 1951). A log-Pearson III frequency curve with zero skew that fits 39 years (1935-58, 1960-74) of annual highest tides at Neah Bay indicates that the 100-year tide level is 12.0 feet (MLLW).

TABLE 1.--Tidal elevations in the Puget Sound region at selected locations

Tidal station or location	National Ocean Survey identifi- cation number <sup>b</sup>	Tidal elevations (feet above mean lower low water)			MLLW <sup>a</sup> to NGVD adjust- ment (in feet)
		12/15/77 high water	Mean		
			higher water	Mean higher tide level	
Tatoosh Island	(42)				
Neah Bay	944 3090 (43)	8.8	7.90	4.30	
Seku	944 3361 (44)		7.90	4.35	4.22
Crescent Bay	944 3826 (45)		7.70	4.30	4.12
Ediz Hook	944 4122 (46)		6.70	4.05	4.07
Twin Rivers	944 3644 (46A)		7.10	4.50	
Port Angeles	944 4090 (47)		7.00	4.10	
Dungeness Bay	944 4471 (48)	9.5	7.20	4.40	3.91
Washington Harbor	944 4555 (49)		7.60	4.70	
Sequim Bay	944 4581 (49A)		7.90	4.80	4.24
			7.80	4.65	
Gardiner Landing	944 4705 (50)	10.2	7.90	4.80	4.31
Cape George	944 4743 (50A)		7.70	4.65	
Port Townsend	944 4900 (51)	11.5	8.60	5.25	4.74
Admiralty Head	944 7905 (52)		8.40	5.10	4.59
Bush Point	944 7854 (52A)	13.2	8.90	5.35	
Fort Flagler	944 4972 (53)		8.80	5.25	
Mystery Bay	944 4971 (53A)		8.20	5.00	
Port Ludlow	944 5017 (54)		9.90	5.90	
Port Gamble	944 5059 (55)	14.0	10.30	6.05	5.58
Lofall	944 5088 (56)		10.40	6.10	
Bangor	944 5133 (57)		10.80	6.40	
Zelatched Point	944 5269 (57A)	16.4	11.50	6.70	
Quilcene					
Whitney Point	944 5246 (57B)		11.20	6.55	
Seabeck	944 5303 (58)	14.6	11.40	6.70	
Pleasant Harbor	944 5293 (58A)		11.60	6.75	6.29
Eldon					
Union	944 5478 (59)	15.1	11.80	6.85	6.38
Lynch Cove Dock	944 5441	15.2	12.10	7.10	
Hansville	944 5526 (59A)	15.7	10.30	6.05	
Kingston	944 5639 (60)	13.8	11.10	6.55	
Point Jefferson	944 5683 (61)		10.90	6.45	
Port Madison	944 5753 (62)		11.40	6.65	6.20
Port Blakely	944 5913 (64)		11.50	6.70	6.12
Pleasant Beach	944 5919 (65)		11.50	6.70	6.16
Brownsville	944 5832 (66)		11.70	6.80	
Poulsbo	944 5717 (67)	15.4	11.90	6.95	6.55
Bremerton	944 5958 (68)	15.2	11.70	6.80	6.35
Tracyton	944 5901 (69)		12.30	7.10	
South Colby-Harper	944 5993 (70)		11.40	6.70	6.25

Tidal station or location	National Ocean Survey identifi- cation number <sup>b</sup>	Tidal elevations (feet above mean lower low water)			MLLW <sup>a</sup> to NGVD adjust- ment (in feet)
		12/15/77 high water	Mean		
			higher water	Mean higher tide level	
Burton	944 6273 (71)	15.6	11.90	6.90	6.47
Gig Harbor	944 6369 (72)	16.3	11.80	6.90	
Arlotta	944 6491 (73)		13.00	7.45	
Wauna	944 6291 (74)	16.6	13.10	7.50	6.82
Longbranch	944 6638 (76)	18.1	13.50	7.75	
Vaughn	944 6366 (77)		14.10	8.10	
Allyn	944 6281 (78)	17.7	14.10	8.10	7.58
Walkers Landing	944 6489 (79)		14.30	8.15	7.84
Arcadia	944 6666 (81)	18.9	14.40	8.20	
Shelton	944 6628 (83)	18.9	14.20	7.90	6.95
New Kamille	(84)	18.8	15.00	8.50	
Eld Inlet	(85)	18.6	14.70	8.40	8.04
Boston Harbor	944 6800	18.4			
Olympia	944 6969 (86)	18.2	14.40	8.25	7.73
Henderson Inlet					
Dupont	944 6752		14.00	8.00	
Steilacoom	944 6828 (88)		13.40	7.70	
Tacoma	944 6714 (89)	16.7	13.10	7.50	6.91
Des Moines	944 6545 (90)	15.1	11.80	6.85	6.51
Seattle	944 6248 (91)		11.60	6.75	
Edmonds	944 7130 (93)	14.8	11.30	6.60	6.25
Glendale	944 7427 (96)		10.90	6.40	5.89
Mukilteo	944 7814 (97)	14.6	10.90	6.45	5.85
Everett	944 7614 (98)		11.00	6.40	6.05
	944 7659 (99)	14.5	11.10	6.50	6.13
Greenbank	944 7883 (101A)	15.1	11.30	6.60	
Coupeville	944 7929 (102)	14.8	11.50	6.70	6.15
Owney	944 8601 (111)		11.30	6.45	5.62
Cornet Bay	944 7995 (112)	14.6	10.20	6.00	5.44
Deception Pass					
State Park	944 8614 (114)		7.60	4.75	4.41
Anacortes	944 8794 (116)		8.30	5.00	4.42
Cherry Point	944 9424	11.7			
Friday Harbor	944 9880 (122)	10.5	7.70	4.75	4.42
Bellingham	944 9211 (130)		8.60	5.20	4.49
Blaine	944 9679 (131)		9.50	5.65	5.26

<sup>a</sup>To convert elevations that are related to mean lower low water (MLLW) datum to those referenced to National Geodetic Vertical Datum (NGVD), subtract the adjustment value from the "Tidal elevations" given above and from other elevations located at these stations that are referred to MLLW.

<sup>b</sup>Station numbers used in older publications are shown in parentheses.

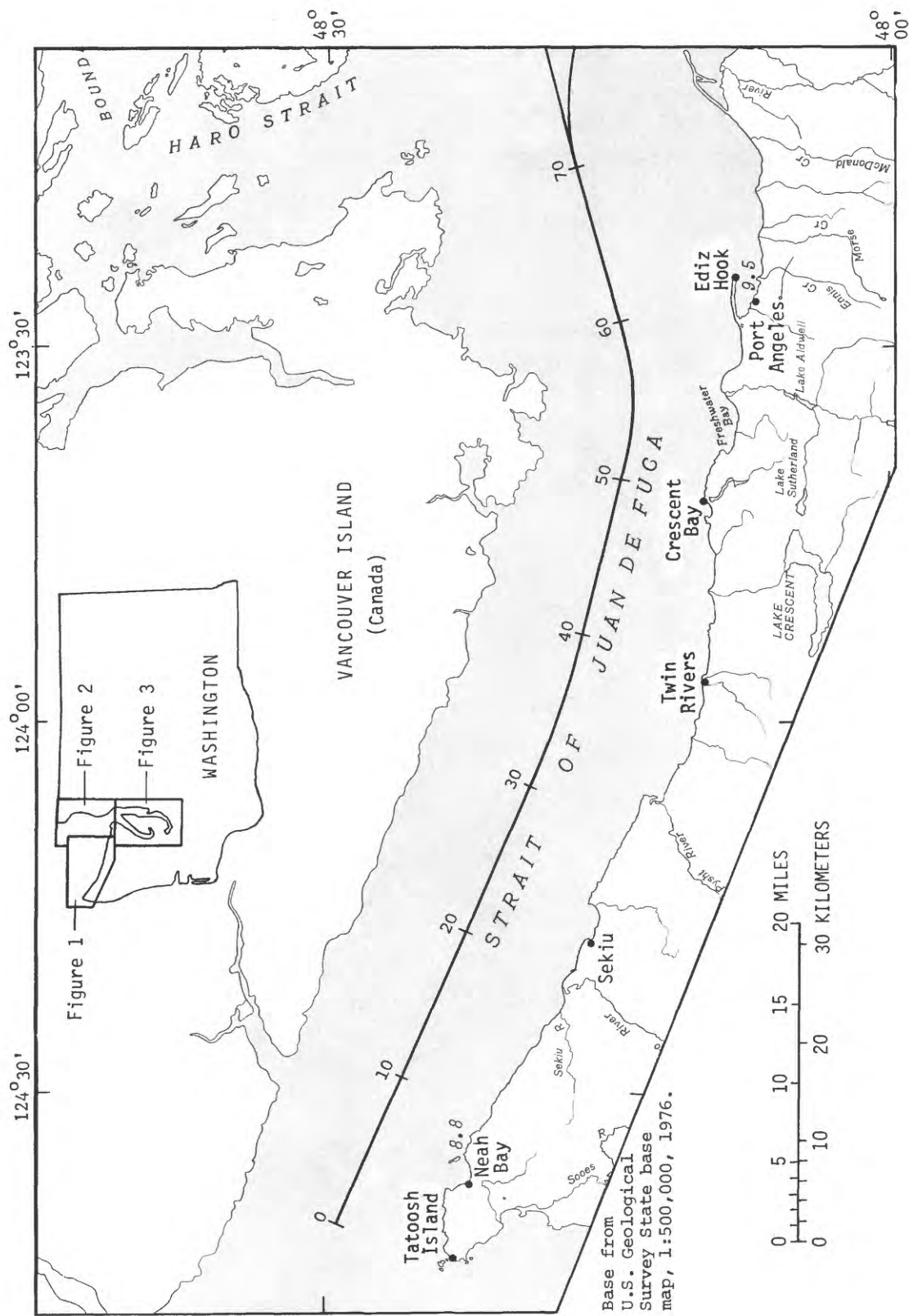


FIGURE 1.--Strait of Juan de Fuca, showing maximum tidal elevations in feet above mean lower low water on December 15, 1977, at two sites, and location of selected tidal stations. (Baseline indicates estimated miles inland from Tatoosh Island.)



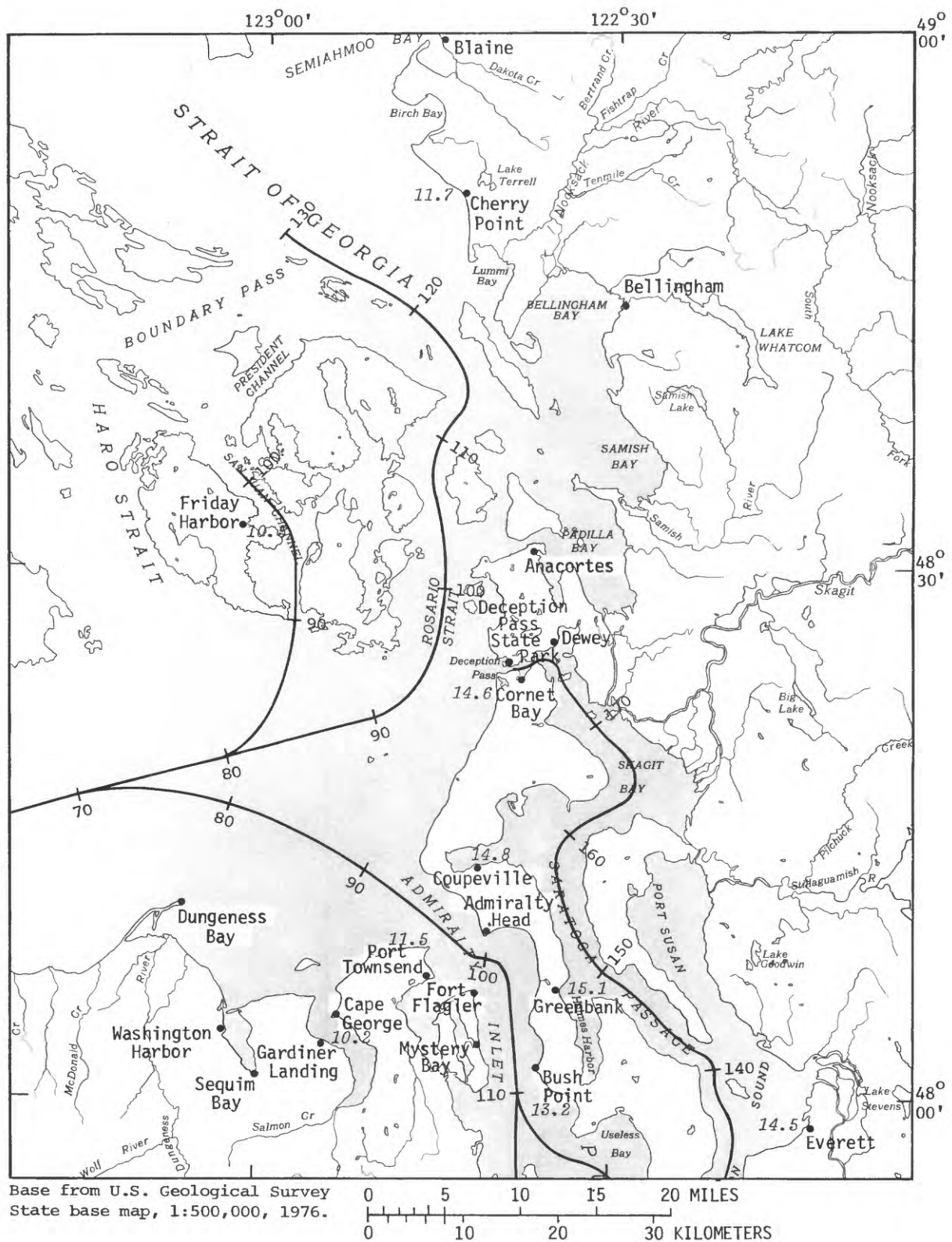


FIGURE 2.--Straits north of Puget Sound, showing maximum tidal elevations in feet above mean lower low water on December 15, 1977, at eight sites, and locations of selected tidal stations. (Baseline indicates estimated miles inland from Tatoosh Island.)

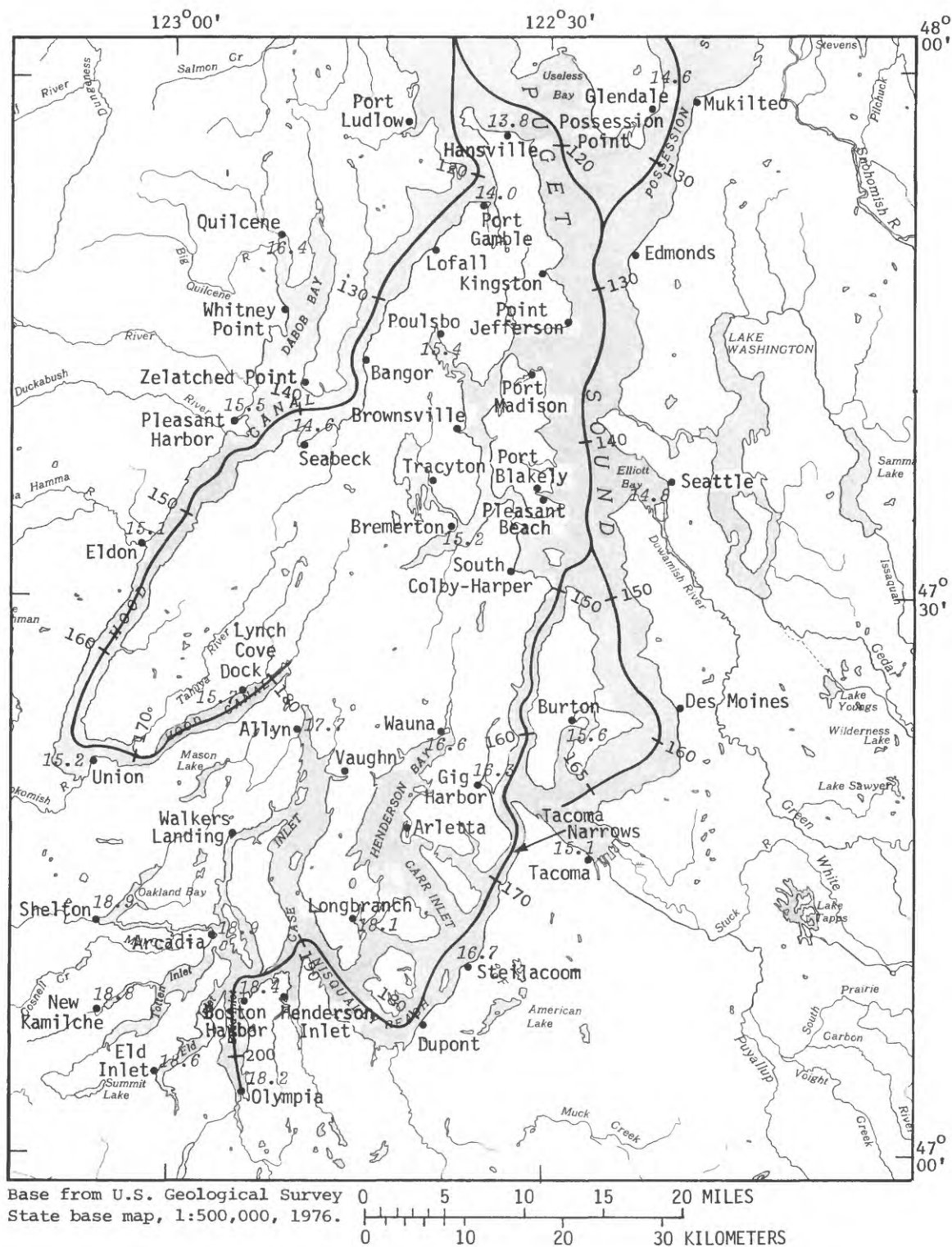


FIGURE 3.--Puget Sound, showing maximum tidal elevations in feet above mean lower low water in December 15, 1977, at 25 sites, and locations of selected tidal stations. (Baseline indicates miles inland from Tatoosh Island.)

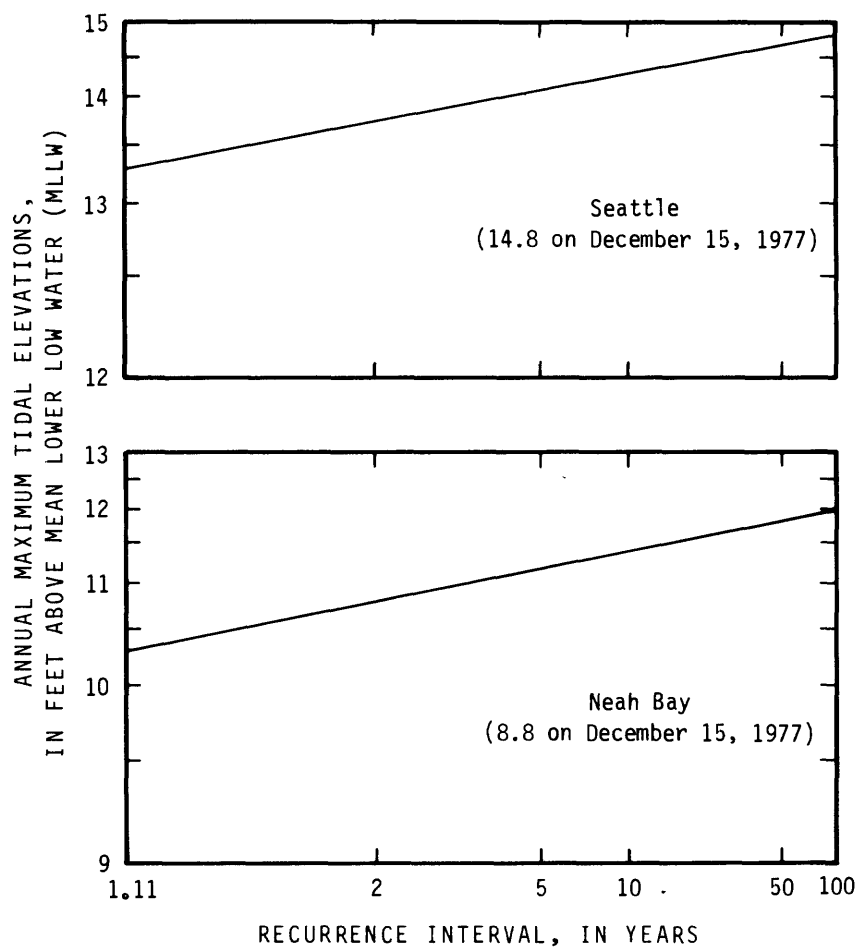


FIGURE 4.--Tidal-frequency curves for Seattle and Neah Bay, Wash.

## TIDAL-ELEVATION PROFILES

Elevations of selected tide levels and the December 15, 1977, high tide were plotted and represented as smooth elevation profiles (figs. 5-8) using distances inland from Tatoosh Island measured along the baselines shown in figures 1-3. The baselines generally follow political boundaries and represent the approximate centerlines of the channels in figure 1-3. These distances are thus an approximation of the travel distances inland from Tatoosh Island.

The elevations shown in figures 5-8 are in MLLW datum; MLLW is elevation zero for tide levels. More tide levels are shown as elevation profiles in these figures than are given as elevations in table 1. The additional profiles for mean low water and mean high water represent tide levels commonly used and defined in marine navigation books and tide tables, and were obtained from NOS tide station records (unpublished data, National Ocean Survey, Seattle, Washington). The additional profile for the December 15, 1977, predicted high tide was estimated from NOS 1977 tide tables by using NOS difference or ratio values (these are obtained from National Ocean Survey in Seattle, Washington) to transfer NOS-predicted high tides for that date at Aberdeen, Port Townsend, or Seattle, as appropriate, to other tide stations.

Predictions of tide elevations are generally based on astronomical data under average weather conditions, and include the effect of average seasonal variations in sea level. Actual tide elevations differ from those predicted because day-to-day changes in winds and barometric pressure cause variations in sea level from the average seasonal level. Generally, onshore winds or low barometric pressure can produce tide levels higher than predicted, and offshore winds or higher barometric pressure can produce tide levels lower than predicted. On December 15, 1977, the observed high tide was much higher than predicted in most of the Puget Sound region, primarily as a result of a very low barometric pressure; very little wave action from wind was observed.

Although 100-year tide elevations were determined for this report at only two locations, Seattle and Neah Bay, estimates of 100-year elevations can be made for many tide stations by using the NOS transfer values from table 2 in "Tide Tables 1977" (Department of Commerce, 1976). Comparison with the 100-year tide elevation for Seattle and the NOS transfer values from Seattle suggests that the December 15, 1977, tide was higher in Puget Sound, ranging from about 0.1 foot higher at Seattle to about 0.4 foot higher at Olympia and about 1.4 feet higher at Shelton. It was also higher in Hood Canal, about 0.1 foot at Union, and about 0.6 foot at Port Gamble. In Saratoga Passage, it was about equal to the 100-year tide at Everett, about 0.1 foot lower at Coupeville, and about 1.5 foot higher at Cornet Bay.

For tidal stations on the Strait of Juan de Fuca, Rosario Strait, and the Strait of Georgia, the NOS high-water transfer values are based on relationships with Aberdeen or Port Townsend tide levels. Frequency analyses were not made for annual highest tides at either Aberdeen or Port Townsend, however, because the tide records at those stations are insufficient in length. To obtain some approximation of 100-year tidal elevations in the three straits, the 100-year tide level at Neah Bay was transferred to Port Townsend and adjusted on the basis of the relationship between tide levels at those two stations. On the basis of the estimated 100-year tidal elevation for Port Townsend and the NOS transfer values from Port Townsend, the December 15, 1977, tide was much lower in the three straits—3.2 feet lower at Neah Bay and approximately 2 feet lower at Port Angeles, 1 foot lower at Port Townsend, 0.5 foot lower at Anacortes, and 1 foot lower at Friday Harbor.

The elevation of most high tides and the range of elevations from low tide to high tide generally increase from mile 50 in the inland direction in the Puget Sound region (figs. 5-8). However, the high tide of December 15, 1977, did not appear to develop a least-height near mile 50.

Noticeably abrupt changes in tidal elevation occur at Admiralty Inlet and at the Tacoma Narrows (fig. 5), and at Deception Pass (fig. 7). These changes are due to constrictions in width and depth. The constrictions have an effect on both ingoing and outgoing tidal flows, but the highest elevations are produced on the outgoing tide. The constrictions in depth are sills - in Admiralty Inlet at about 210-foot depth, in the Tacoma Narrows at about 150-foot depth, and in Deception Pass at about 100-foot depth. About 24 percent of the water entering the eastern half of the Strait of Juan de Fuca flows through Admiralty Inlet into Puget Sound (Schumaker, 1978). About 98 percent of the water flowing into Puget Sound enters through Admiralty Inlet, and 2 percent through Deception Pass (Cannon and Laird, 1978).

## PREVIOUS STUDIES

"Approximate 100-year frequency tide elevations" and "approximate tide elevations observed on December 15, 1977" are shown on the Department of Ecology maps (State of Washington Department of Ecology, 1979) for Island, King, Mason, Pierce, Snohomish, and Thurston Counties, and the approximate extent of coastal flooding is shown for all the 12 counties in the Puget Sound region. The "approximate 100-year frequency tide elevations" were calculated by adding the difference between mean high water and (100-year) December 15, 1977, high tide elevations at Seattle to the mean high water elevations at the other tidal stations in the region. "The approximate tide elevations observed on December 15, 1977," were obtained by transferring the values from one of the NOS recording stations operating on December 15, 1977. Due to differences in the methods of determining elevations for the December 15, 1977, high tide and the 100-year tide, values shown on the Department of Ecology maps differ from those in this report for some locations.

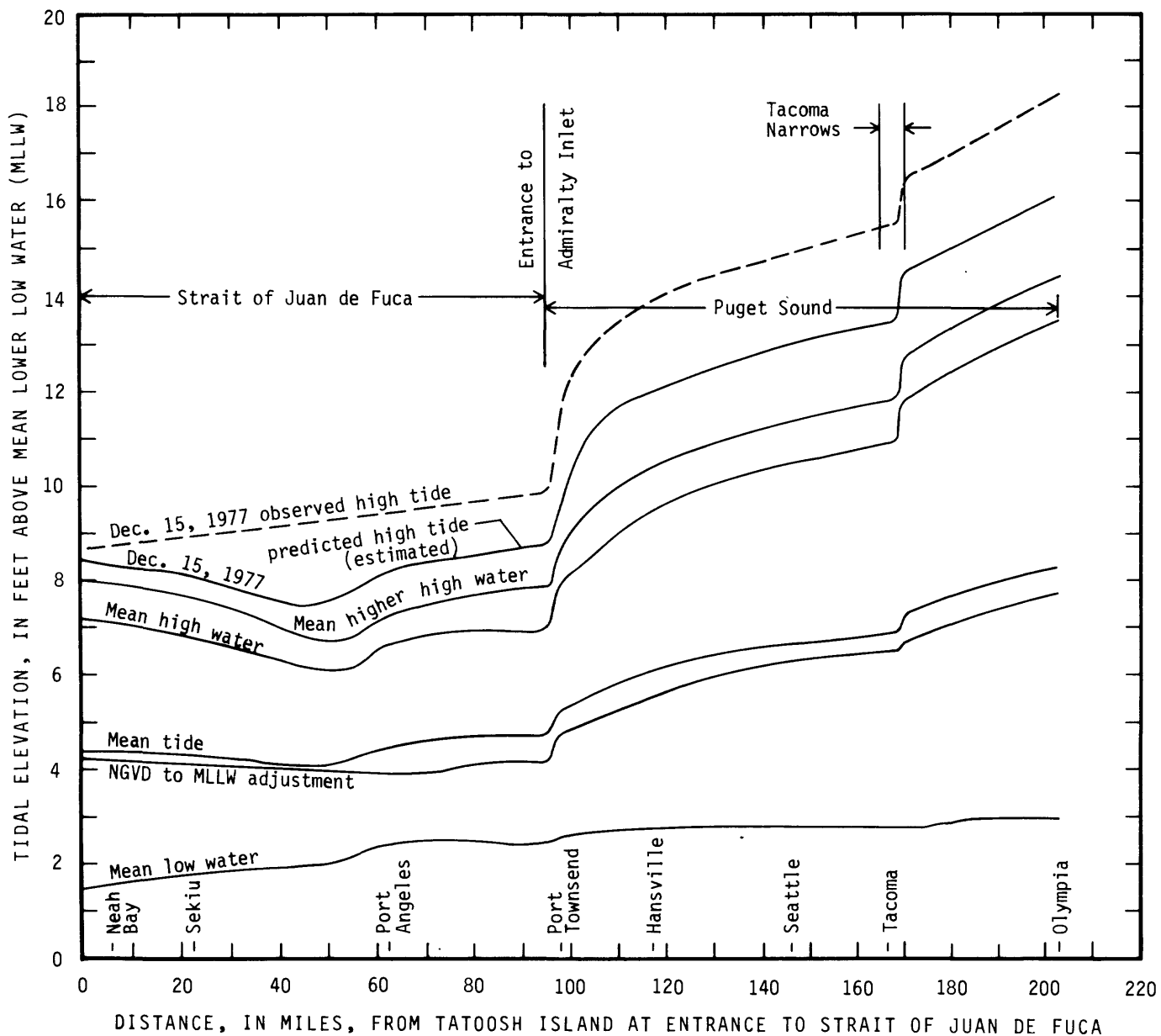


FIGURE 5.--Tidal-elevation profiles for the Strait of Juan de Fuca and Puget Sound showing relation of December 15, 1977, observed high tide to other tide heights.

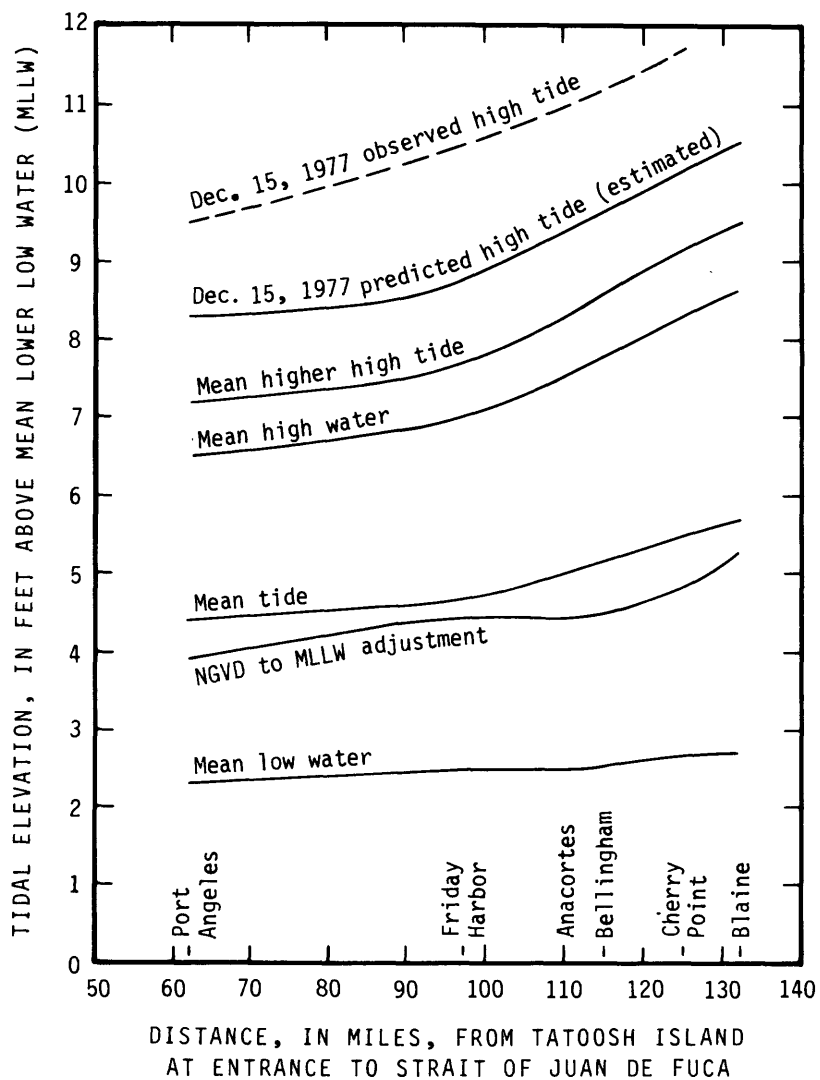


FIGURE 6.--Tidal-elevation profiles for Strait of Juan de Fuca, Rosario Strait, and Strait of Georgia from Port Angeles to Anacortes showing relation of December 15, 1977, observed high tide to other tide heights.

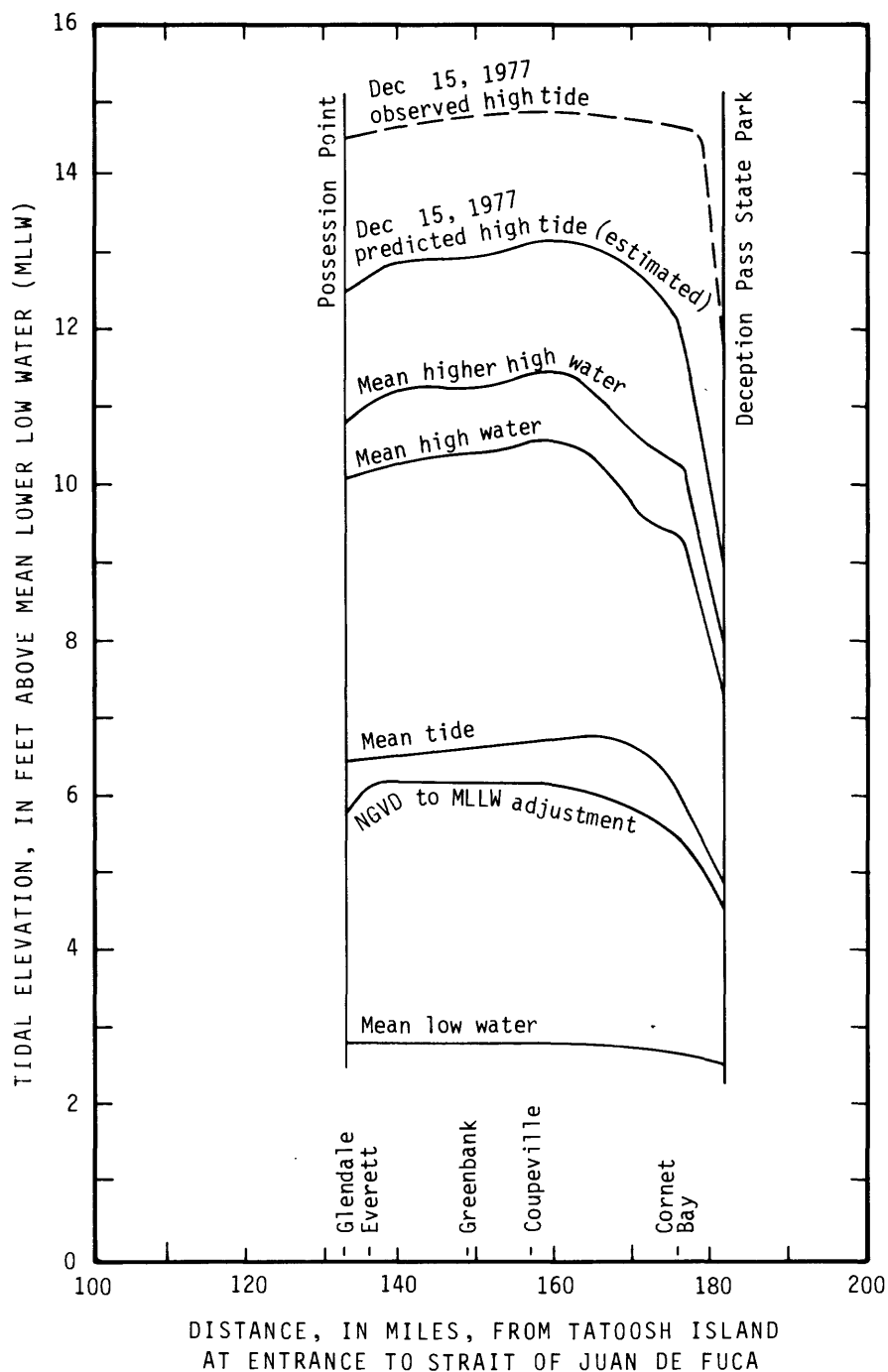


FIGURE 7.--Tidal-elevation profiles for Saratoga Passage showing relation of December 15, 1977, observed high tide to other tide heights.



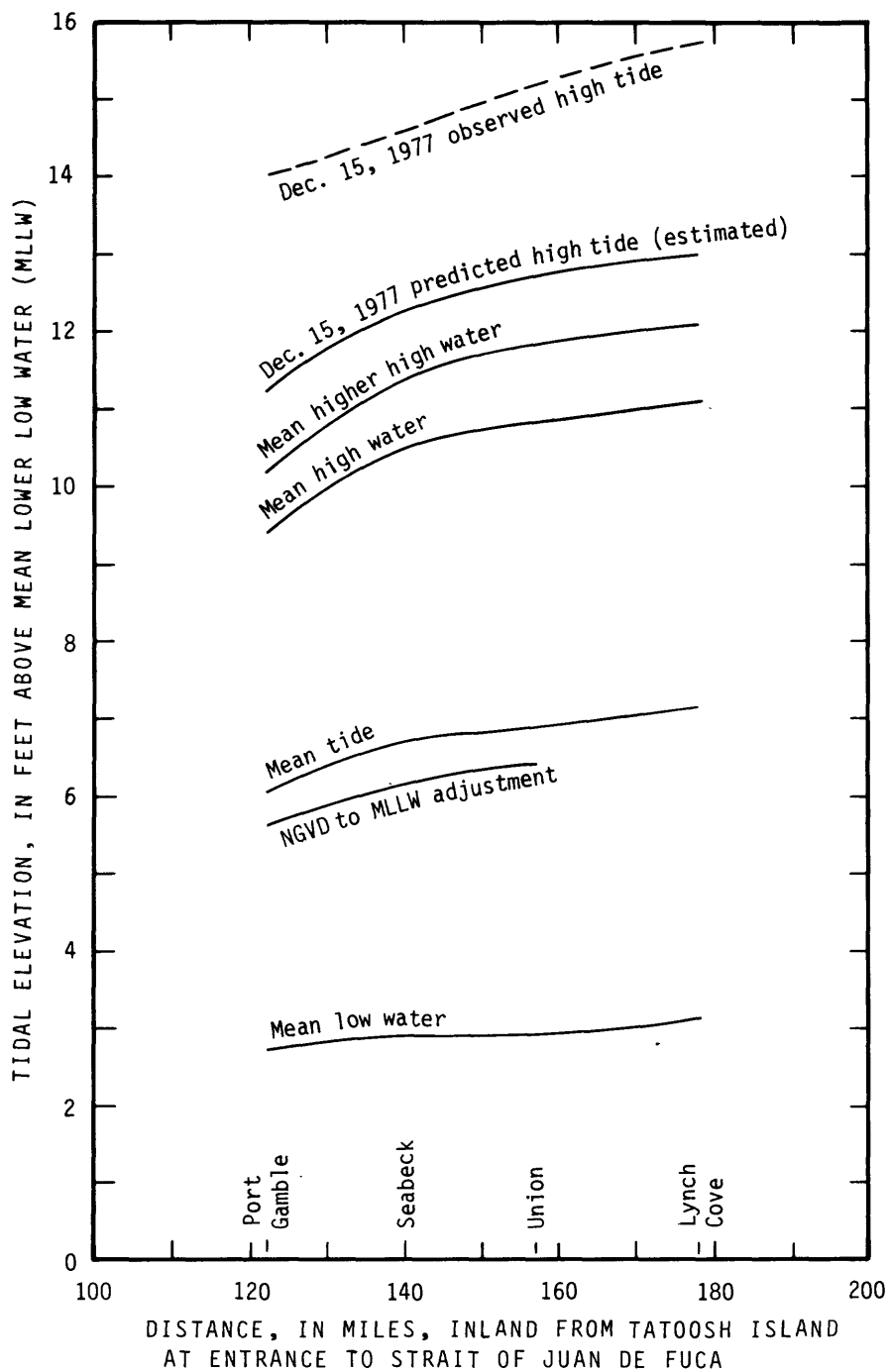


FIGURE 8.--Tidal-elevation profiles for Hood Canal showing relation of December 15, 1977, observed high tide to other tide heights.

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